Heights of rivers above zeros of gauges—Continued.

Stations.	Distance to mouth of river.	Danger-line on gauge.	Highest water.		Lowest water.		Mean stage.	Monthly range.
			Height.	Date.	Height.	Date.		
Cumberland River.	*Miles.*	*Feet.*	*Feet.*		*Feet.*		*Feet.*	*Feet.*
Burnside, Ky	434	50	18.0	15	0.8	3	5.1	17.2
Carthage, Tenn..........	257	30	15.9	18	2.0	3	6.8	13.9
Nashville, Tenn	175	60	20.9	18	3.0	3	10.1	17.9
Great Kanawha River.								
Charleston, W. Va.......	61	30	5.8	23	3.2	29–31	5.0	2.6
New River.								
Radford, Va.............	153	14	1.0	22, 23	0.3	13, 14	0.5	0.7
Hinton, W. Va...........	93	14	2.6	23, 24	1.1	30, 31	1.9	1.5
Licking River.								
Falmouth, Ky.[a].........	30	25	6.5	21	1.6	11–14	2.9	4.9
Miami River.								
Dayton, Ohio	69	18	2.8	5	1.2	2, 3	1.6	1.6
Monongahela River.								
Weston, W. Va.[c] ;......	161	18	1.5	5	0.0	{1–4, 8–20? 26–28}	0.2	1.5
Fairmont, W. Va	119	25	4.4	19	1.3	15, 16	2.2	3.1
Morgantown, W. Va. [P]..	95	20	10.0	19	7.5	14, 15	3.3	2.5
Greensboro, Pa.[q].......	81	18	10.5	19, 20	7.6	31	8.6	2.9
Lock No. 4, Pa...........	40	26	10.8	19, 20	6.7	29–31	8.4	4.1
Cheat River.								
Rowlesburg, W.Va.[r]...	36	14	5.5	18	2.4	1	2.4	3.1
Youghiogheny River.								
Confluence, Pa.........	59	10	3.9	5, 18	1.5	16, 30	2.4	2.4
West Newton, Pa........	15	23	3.4	22	1.0	1, 2, 16, 17	2.0	2.4
Tennessee River.								
Knoxville, Tenn.........	614	29	2.5	15, 16, 18	0.8	3, 10–13	1.7	1.7
Chattanooga, Tenn......	430	33	7.3	23	2.4	1, 18	4.4	4.9
Bridgeport, Ala........	390	......	5.6	22, 23	1.1	1–4	2.9	4.5
Florence, Ala..........	220	16	6.5	23	1.0	3	3.3	5.5
Johnsonville, Tenn......	94	21	10.6	22, 23	2.6	4	5.8	8.0
Rockwood, Tenn	519	20	6.1	23	1.7	12, 13	3.4	4.4
Wabash River.								
Terre Haute, Ind.[s]......	165	16	14.5	6, 7	1.7	1	8.7	12.8
Mt. Carmel, Ill.[t].........	50	15	13.9	23	2.9	2	9.7	11.0
Red River.								
Arthur City, Tex.........	688	27	20.6	4	2.6	1	6.0	18.0
Fulton, Ark	565	28	21.8	7	1.2	1, 2	10.0	20.6
Shreveport, La..........	449	29	10.0	11	−1.8	1, 2	6.8	11.8
Alexandria, La	139	33	15.0	21, 22	−0.9	1	9.7	15.9
Atchafalaya River.								
Melville, La.............	100	31	25.0	31	13.2	1	19.9	11.8
Ouachita River.								
Camden, Ark............	340	39	30.5	8	4.1	1	19.3	26.4
Monroe, La	100	40	24.6	30, 31	2.8	1	18.7	21.8
Yazoo River.								
Yazoo City, Miss.........	80	25	7.6	31	−1.8	1, 2	3.8	9.4
Tombigbee River.								
Columbus, Miss.........	285	33	6.0	19	−2.7	1	0.7	8.7
Demopolis, Ala.[v]........	155	35	20.6	22	−0.9	1–3	7.1	21.5
Black Warrior River.								
Cordova, Ala	155	20	11.7	18	2.2	1–3	4.8	9.5
Tuscaloosa, Ala..........	90	38	19.3	19	0.3	1	6.5	19.0
Alabama River.								
Montgomery, Ala........	265	35	13.0	22	0.4	2, 3	3.7	12.6
Selma, Ala...............	212	35	14.8	23	0.2	1, 2, 15–17	4.0	14.6

Heights of rivers above zeros of gauges—Continued.

Stations.	Distance to mouth of river.	Danger-line on gauge.	Highest water.		Lowest water.		Mean stage.	Monthly range.
			Height.	Date.	Height.	Date.		
Coosa River.	*Miles.*	*Feet.*	*Feet.*		*Feet.*		*Feet.*	*Feet.*
Rome, Ga	225	30	9.5	23	0.9	11–13	2.9	8.6
Wilsonville, Ala	66	15	....	....	....	....	......	......
Tallapoosa River.								
Sturdevant, Ala	69	15	....	....	....	....	......	......
Savannah River.								
Augusta, Ga	130	32	20.8	22	5.8	13	9.0	15.0
Edisto River.								
Edisto, S. C	75	6	4.7	22	2.4	12, 13	3.4	2.3
Congaree River.								
Columbia, S. C..........	37	15	7.0	22	0.8	3, 8–13	2.2	6.2
Santee River.								
St. Stephens, S. C.........	50	12	7.8	31	2.0	14	4.5	5.8
Wateree River.								
Camden, S.C	45	24	18.0	22	3.1	8	5.7	14.9
Black River.								
Kingstree, S. C...........	60	12	6.6	30, 31	3.3	14	5.2	3.3
Great Pee Dee River.								
Cheraw, S. C.............	145	27	21.4	22	1.8	13	4.3	19.6
Linch Creek.								
Effingham, S. C	35	12	7.6	30	4.4	13	5.5	3.2
Lumber River.								
Fairbluff, N. C	10	6	4.0	1	2.9	31	3.2	1.1
Waccamaw River.								
Conway, S. C	40	7	5.3	1	2.2	17	3.4	3.1
Cape Fear River.								
Fayetteville, N.C........	100	38	24.0	22	4.0	13	7.7	20.0
James River.								
Lynchburg, Va.[u].........	257	18	1.0	22, 23	0.4	1–4, 10–13	0.6	0.6
Richmond, Va...........	110	10	....	....	....	....	.....	......
Potomac River.								
Harpers Ferry	170	16	....	....	....	....	.....	...
Susquehanna River.								
Wilkesbarre, Pa.........	178	14	....	....	....	....	.....	......
Harrisburg, Pa..........	70	17	3.7	7–9	0.5	26	2.5	3.2
W. Br. of Susquehanna.								
Lock Haven, Pa..........	63	......	2.0	8	0.5	27–31	1.1	1.5
Williamsport, Pa........	35	20	3.9	6	1.4	21	2.3	2.5
Juniata River.								
Huntingdon, Pa..........	80	24	4.9	5	3.4	22–31	3.6	1.5
Sacramento River.								
Redbluff, Cal	241	23	14.0	29	2.0	20–27	4.1	12.0
Sacramento, Cal	70	28	20.0	31	14.5	28, 29	16.3	5.5
Willamette River.								
Eugene, Oreg	149	10	7.6	1	3.2	17	4.5	4.4
Albany, Oreg	99	20	10.8	2	4.2	18	6.0	6.6
Salem, Oreg............ ..	69	20	9.6	1	7.4	16, 26	8.1	2.2
Portland, Oreg...........	10	15	8.7	3	3.0	15, 16	5.5	5.7

*Distance to the Gulf of Mexico. †Frozen. [a]Frozen 23–31. [b]Frozen 26–31. [c]Frozen 29–31. [d]Frozen 26, [e]Frozen 29. [f]Frozen 30–31. [g]Frozen 28–31. [h]Frozen 5–9. [i]Frozen 25–31. [j]Frozen 25–31. [k]Frozen 26–31. [l]Frozen 25–31. [m]Frozen 26–31. [n]Frozen 28–31. [o]Frozen 29–31. [p]Frozen 13, 25–31. [q]Frozen 25. [r]Frozen 15, 16, 25, 31. [s]Frozen 25–31. [t]Frozen 29–31. [u]Frozen 26–31. [x]Frozen 31. [v]No observation 15–18.

SPECIAL CONTRIBUTIONS.

CLOUD OBSERVATIONS AND MEASUREMENTS AT THE BLUE HILL METEOROLOGICAL OBSERVATORY, MILTON, MASS.

Communicated by A. LAWRENCE ROTCH, Director (dated February 22, 1897).

Nephoscope observations of direction and relative velocity are made on Blue Hill three times a day in cooperation with the network of stations of the United States Weather Bureau. Nephoscope observations have been made on Blue Hill three times a day, or oftener, since 1887.

There are three theodolite stations in the same straight line, furnishing three bases, respectively of 2,590 meters, 1,178 meters, and 1,412 meters, from the ends of some one of which simultaneous observations for height and velocity are made twice a day when conditions permit. These observations were re-commenced May 1, 1896, and have been obtained on about eighty days in each one hundred. The differences in level between the ends of the base lines are 189, 126, and 63 meters, in the order given above. Two of the theodolites are similar to those first used by Mohn for measuring auroras, and the third theodolite is a surveyor's transit remodeled to conform to this pattern. In making observations, points on the clouds are selected by telephonic communication, and, when practicable, from three to five observations are taken on the same point, at intervals of a minute. Three or more points are selected successively on the same kind of clouds, in different parts of the sky, in order to avoid the error which may arise from the observers at the same moment following different clouds or different portions of the same cloud, and also in order to obtain a better knowledge of the mean height of the same cloud stratum.

The observations are reduced by the simple trigonometrical formulæ. All poor observations are discarded, as well as those made when the cloud was near the horizon or near the base line.

The theodolite measurements at two stations are supplemented by four other methods, devised by Mr. Clayton, to determine the height of the lower clouds; these are:

1. Measurements at one station of the positions of the cloud, sun, and cloud shadow from which the height can be calculated.

2. Sending up kites and measuring the amount of line and the angle of the kite above the horizon when it enters the base of the cloud.

3. Measuring from Blue Hill, the angular altitude of light reflected at night on clouds above cities whose distances are known.

4. Noting the height of the base of low clouds on the side of Blue Hill.

The first two methods are used frequently, the last two only

occasionally. The necessity of these additional methods is proved by the fact that the average height of nimbus and strato-cumulus from theodolite measurements alone is considerably more than 1,000 meters, while measurements with kites show that on more than half of the days on which these clouds are present their bases are below 1,000 meters and usually below 500 meters. The reason is that low clouds are so indefinite in form, or cover the sky with such a uniform veil, that it is impossible to measure them with theodolites or photogrammeters.

EXCESSIVE PRECIPITATION IN THE UNITED STATES.
By ALFRED J. HENRY, Chief of Division.

Vast sums of money are expended each year in the construction of sewers and drainage systems. In the designing of main sewers for large areas a thorough knowledge of the vicissitudes of rainfall of the region, particularly as regards the intensity and duration of the heavier falls, is essential.

A number of quite heavy rainstorms occurred during the past year, and in a number of cases the capacity of the sewers was not equal to the task of discharging the accumulated storm waters. Failure of sewers to carry off flood waters is not a new problem in municipal engineering, though it has cost in damage to property and resulting litigation many thousands of dollars.

At the request of a number of civil and municipal engineers, Prof. Willis L. Moore, Chief of Bureau, has directed that statistics of unusually heavy rains be published in greater detail than heretofore. The facts and figures herein presented may be considered as a first attempt to draw some useful deductions from the records of automatic rain gauges in use at Weather Bureau stations.

Excessive rains naturally fall into two broad classes, (a) rains of great intensity and short duration, and (b) light intensity and long duration. Of these two classes, those of the first are by far the most damaging and destructive. In extreme cases 95 per cent of the downpour may quickly find its way into natural or artificial drainage channels. A rainfall of one-half inch in linear depth represents about 11,312 imperial gallons per acre. Assuming that in extreme cases only 5 per cent is absorbed, it is easily seen how great a quantity of water must flow into the drainage channels.

On the Pacific Coast, particularly the coast of Washington and Oregon, where the annual rainfall is greater than in any other portion of the United States, excessive rains of class a are not prevalent. The rain of this region falls principally between September and May, the colder part of the year, when convectional overturning in the atmosphere is least active.

The most favorable conditions for the sudden condensation of a vast quantity of water vapor are conceived to be (1) a strong vertical temperature gradient; (2) high surface temperature and humidity, in fact, the general conditions of humidity and instability of the atmosphere necessary to the formation of thunderstorms and tornadoes.

The most violent rains of class a, and, at the same time, those of which the least is known, are the so-called cloudbursts of the mountainous and arid regions of the west. These storms are not confined to any particular state or region but may occur in mountainous localities throughout the entire territory bounded by the British possessions on the north, the Mexican border on the south, the foothills of the Rockies on the east and the Sierras on the west. In the true cloudburst the rain seems to pour down rather than fall in drops, and, as a rule, the downpour of water covers an extremely small area. It often happens that the downpour occurs over rather narrow basins or on mountain slopes whose outlets are canyons or gorges leading to a valley or plain below. In these cases almost the entire amount of water quickly finds its way into the drainage channel, and, as a result, a wave of water rushes down the outlet with considerable velocity and in sufficient volume to destroy everything in its path. Such a flood wave almost swept away the town of Eureka, Nev., in 1874, and caused the loss of 15 lives. A far greater disaster occurred in Bear Creek Canyon, Colo., in July, 1896. Thirty lives were lost and property valued at more than $100,000 was destroyed.

The amount of rain that falls in one of these torrential downpours has never been ascertained. A cloudburst passed over the edge of the little town of Palmetto, Nev., in August, 1890. A rain gauge that was not exposed to the full intensity of the storm caught 8.80 inches of water in an hour. In August, 1891, two storms passed over Campo, Cal., within a few minutes of each other. The second storm was a veritable cloudburst. The observer succeeded in measuring the rainfall of the first shower and a portion of the second. Eleven and a half inches were measured within an hour. The rain gauge and support were carried away by the torrent of water in the second storm and the full record was not obtained.

The great majority of excessive rains (class a) in the United States occur east of the one hundred and fifth meridian, and principally in the summer months. They are most frequent in connection with summer afternoon thunderstorms, but occasionally occur in the track of West India hurricanes. They are more abundant on the Gulf and south Atlantic coasts than at inland points.

In Table A there are given the essential facts concerning each excessive rain of which permanent record was made during 1896, at stations equipped with self-recording rain gauges. Columns 1 and 2 give the total duration of the storm; column 3, the total depth of rainfall; columns 4 and 5, the beginning and ending, respectively, of the excessive rate; column 6, the amount of rain that fell before the excessive rate began. In the succeeding colums the accumulated amounts of rainfall are given for each successive five minutes of the storm's duration up to fifty minutes, and in ten and twenty minute periods thereafter.

It is possible to determine from the details thus presented whether or not rain falls at a uniform rate and how long such rate continues, and also the approximate time when the flow in the sewers shall be at a maximum for any given rate.

It is generally assumed that in heavy showers the intensity, i, varies inversely as the duration, t, and a number of formulæ have been suggested to express the relation between i and t. From an examination of the data in Table A, it would seem to be extremely doubtful whether a relation sufficiently definite to admit of expression by mathematical formulæ exists. The general principle that rains of the highest intensity exhaust themselves quickly holds good, but the fact remains that the total duration of the storm bears no simple relation either to the rate or linear depth of rainfall.

Percentage of cases in which the maximum intensity of rainfall occurred within five to sixty minutes from the beginning of the storm.

Maximum intensity occurred.	Washington.	Savannah.	St. Louis.
	Per cent.	*Per cent.*	*Per cent.*
Within 5 minutes from beginning of storm....	17	10	32
" 10	21	20	30
" 15	20	21	8
" 20	5	13	5
" 25	8	7	2
" 30	9	10	2
" 35	5	5	2
" 40	5	1	8
" 45	2	4	5
" 50	1	5	5
" 60	6	3	2

The periods of very great intensity are of short duration and may occur at any time during the continuance of the storm. There may be two and even three periods of great intensity in a single storm separated by intervals of light